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## On the absence of pupillary constriction during accommodation

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## SUMMARY

During near vision the eyes focus through additional curvature of the eye lenses, the eyes converge on the near object and the pupils constrict: the near triad. Increase of depth of focus and/or decrease of lens aberrations do not sufficiently account for the pupillary reaction.

Neither can the pupillary reaction be accounted by the change of light (which occurs during object approach) impinging on the retina. The change of light is too small and too shortlived for that. Moreover, pupillary constriction persists during near vision.

According to the hypotheses most investigated and discussed, pupillary constriction can be evoked by either neural stimulation driving accommodation or neural stimulation driving vergence, or a separate drive which becomes active during near vision. Although these discussions are not settled, current theories allege that innervation of the sphincters is connected with the neural input which produces accommodation and, probably, with the neural input activating vergence.

When recording Visual Evoked Potentials, evoked by far-near stimulation, we observed that pupillary reaction was occasionally absent. This was in flat contradiction to the near triad and required further research. Because the pupil is responsive to changes in retinal luminous incidence, both "spatial and temporal", the stimulus producing accommodation had to be free of spurious elements. It appears that the pupillary reactions during accommodation of all five subjects were much smaller than encountered in literature, but not entirely reproducible. Occurrence of accommodation was verified by the recording the fellow eye and confirmed by measuring the change of Purkinje III images. Irreproducibility, we assumed, was caused by an unknown parameter concealed in the stimulus ensemble.

Further investigation showed pupillary responsiveness was associated with the pseudo movement arising when far and near targets were not sufficiently aligned with the viewing eye. Alignment is the unknown parameter: accommodative pupillary reaction is absent during perfect alignment, and pupillary reaction increases as misalignment increases. We must conclude that during near vision the pupil, if at all, is driven by centres that function independently of accommodation.

Chapter 1 briefly relates how the research was started and proceeded. The near triad is discussed as well as the pupillary role within it. Furthermore the ambiguous use of terms employed in the literature are dealt with. Several terms, such as accommodation (con-, di-)vergence are used without being defined by authors, and represent either a state [A], a change of state [B], or a process [C]. Examples from

literature are given. Both in the thesis and in this summary it will be indicated which of the three categories is meant.

Chapter 2 deals with the structure of the iris, innervation of the two iris muscles and pupillary dynamics. Because of threefold partial crossings of the afferent pathways, the light reaction is consensual. Pupillary behaviour in response to light (flashes) and to dark (flashes) is discussed as well as the phasic and sustained response. Pupillary reaction to spatio-temporal stimulation reminds one of the pattern reversal VEP. Pupillary reaction to frequency modulated light, which reminds one of the Brücke effect, as well as the behaviour to non-visual stimuli, such as the eye lid closure reflex, is briefly discussed. It is explained how we dealt with artifact causing reflexes.

Chapter 3 shows some properties of vergence [B]. Maddox divided vergence [B] into qualitatively different components which, when added, represent the entire vergence response: tonic, accommodative and fusional components. Maddox also recognized a component which was related to "knowledge of nearness", and included this component in the accommodative component [B]. The relation between vergence [C] and accommodation [C] is discussed along with accommodative vergence [B] and the occurrence of micro-saccades of the stimulated eye when there is monocular stimulation. The literature shows different latencies of accommodative vergence [B]; the latency of accommodative vergence [B] produced by accommodation [C] is smaller than the latency produced by de-accommodation [C], but still considerable shorter than the latency of accommodation [B] and de-accommodation [B] itself. Because vergence stimuli cause considerable changes of retinal spatio-temporal luminous incidence, vergence stimuli elicit secondary pupillary reactions.

Chapter 4 discusses accommodation [B]. Through contraction of the ciliary muscle, which is a parasympathetically innervated smooth muscle, the zonule relaxes which enables additional curvature of the anterior surface and, to a lesser extent, of the posterior surface of the eye lens. Accommodation [B] is consensual, as is the pupillary reaction and is, like vergence [B], divided into several parts: the tonic, vergence, proximal and reflex components. A brief survey is given of accommodometry and of accommodative latencies produced by monocular blur.

Chapter 5. In 1619 Scheiner described the pupillary constriction during near vision. After that many wondered how the pupil was driven. Experimental results are contradictory and have led to heated discussions. On the grounds of neuro-anatomical research, some authors assume a separate, independent cortical drive of the pupil, apart from the light reflex.

Chapter 6 describes quantitative investigations of the pupillary reaction during blur induced accommodation [B]. Blur was produced by moving an object with or without the use of a Badal Optometer. It is shown that in all investigations discussed accessory stimuli, different from blur, occurred. Initial pupillary diameter

determines pupillary sensitivity to light and to accommodation [C] according to a number of researchers: for pupillary diameters of ca. 6 mm the pupillary sensitivity is said to be at its maximum.

In chapter 7 the demands to be met for a purely accommodative stimulus are formulated. An accommodative stimulus without spurious stimuli consists of (monocularly observed) blur, arising when an object is approaching, while the solid angle remains unaltered and while the image of the object does not move across the retina. The stimulated eye has to be kept in darkness, with only the accommodative target visible. The non-stimulated eye has to be kept in complete darkness. Spatio-temporal and temporal retinal changes of luminous incidence must be excluded. White light is used and auditory stimuli are avoided.

Chapter 8 describes the stimulus device and the way pupillography was carried out. The stimulus is realized by alternately transilluminating two targets, one distant and one near, in an otherwise dark environment. Sizes of the targets were proportional to the distances from the viewing eye. By means of a beam splitter the images are optically aligned. Fluorescent lamps are used for light sources. Switching time is kept as short as possible by use of electronic drive circuitry. Pupillography is carried out on the fellow eye by means of an infrared video camera system. This chapter discusses how to establish that correct accommodation [B] has occurred.

Chapter 9 presents the results of the early experiments, carried out with five subjects. Pupillary constrictions of all subjects are significantly smaller than those reported in literature and are even absent in one third of all experiments. The cause of the small pupillary reactions (subdivided in: phasic, sustained and late sustained responses) is inferred to be in an experimental parameter hitherto unknown to us. Micro-saccadic movement of the stimulated eye in one subject is shown. By measuring the vergence response of the fellow eye and the change in size of the Purkinje III image, correct accommodation [B] was confirmed in all subjects.

Chapter 10 presents the final experiments: tracing the unknown parameter. The experimental set-up was modified: three beam splitters were applied to make the light from far and near target undergo an equal number of reflections and transmissions. By using registrations, obtained from the early experiments, it is shown that the pupil proved to be highly sensitive to alignment. For this reason individual bite bars, mounted in a translation stage, were applied. Because alignment accuracy exceeds the ability of the subjects an indirect alignment procedure was developed. This procedure, however, does not guarantee the finding of an optimal alignment position. In some cases such a position was in fact found and the pupillary reaction during accommodation [B] was then absent. Misalignment re-introduces the pupillary constriction monotonically: the greater misalignment the greater pupillary constriction. These results are presented in section 2 of chapter 10, which is a preprint of the author's article "Accommodation without pupillary constriction", in press for publication in *Vision Research*.

Chapter 11, the discussion, introduces reasons advocating that neither the light reflex nor spatio-temporal responsiveness can be held responsible for the accommodative pupillary reaction during misalignment. The difference between static and dynamic alignment is discussed. The suggestion is made that the parietal lobes are able to detect the pseudo movement which arises when there is insufficient alignment. Detection of the pseudo movement makes a significant contribution to the difference in sensitivity in dynamic and static alignment and probably causes the pupillary reaction.

Appendix 1 gives a brief historical review of the optical properties of the eye.

Appendix 2 is a translation, from Latin into English, of Scheiner's second and third experiment, as described in his *Oculus* (1619). Scheiner noticed pupillary constriction during monocular fixation of an approaching needle and also during alternate fixation of a far and a near object (with one eye covered).

Appendix 3 discusses the procedure used to measure accommodation [B] from the change in size of Purkinje III images. This is carried out in four subjects. Purkinje III images are formed by reflection of the anterior surface of the eye lens and thus vary with accommodation [B]. From the ratio between the size of Purkinje III images, photographed during fixation on far and during fixation on near, accommodation levels [A] can be established. The algorithm used by the computer program is described. It is shown that all four subjects did accommodate [B] adequately.

Appendix 4 presents a detailed description of the stimulus set-up, as used for the early experiments. It describes the electronic circuitry used.

Appendix 5, produces abstracts of papers which have been given at: the International Symposium on Evoked Potentials for the Assessment of Central Nervous Disorders, Lausanne, 1984; the Dutch Society of Clinical Neurophysiology, Utrecht, 1988 and the 18th Annual Pupil Colloquium, Berkeley, Calif., 1989.